CANADA-ONTARIO AGREEMENT

PUBLICATIONS

Relating to

SEWAGE SLUDGE PRODUCTION, TREATMENT, HANDLING, UTILIZATION AND DISPOSAL

May, 1979

Revised September, 1981

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Ontario
Ministry of the Environment

The Honourable
Keith C. Norton, Q.C.,
Minister

Graham W. S. Scott, Q.C.,
Deputy Minister

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CANADA ONTARIO AGREEMENT

PUBLICATIONS

Relating to

SEWAGE SLUDGE PRODUCTION, TREATMENT, HANDLING, UTILIZATION AND DISPOSAL

MUNICIPAL AND PRIVATE ABATEMENT SECTION

POLLUTION CONTROL BRANCH

ONTARIO MINISTRY OF THE ENVIRONMENT

MAY, 1979

REVISED: SEPTEMBER, 1981

FOREWORD

This report will be of interest to persons who wish to study the research which was used as a basis for the Ontario Ministry of the Environment's April 1978 publication: "Guidelines for Sewage Sludge Utilization on Agricultural Lands". It lists and includes abstracts of Canada-Ontario Agreement research publications on sewage sludge production, treatment, handling and disposal.

CANADA-ONTARIO AGREEMENT RESEARCH REPORT ABSTRACTS

ON SEWAGE SLUDGE

These abstracts describe research projects funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada/Ontario Agreement on Great Lakes Water Quality. They provide information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of the Environment, and through contracts with municipalities, research institutions and industrial organizations.

The more comprehensive and detailed RESEARCH REPORTS on the projects on which these abstracts are based may be obtained from:

Training and Technology Transfer
Division (Water),
Environmental Protection Service,
Environment Canada,
Ottawa, Ontario
K1A 0H3

Enquiries concerning the technical content of individual reports prepared under the Canada-Ontario Agreement RESEARCH PROGRAM can be directed to

EITHER:

Ontario Ministry of the Environment,
Pollution Control Branch,
135 St. Clair Avenue West,
Toronto, Ontario
M4V 1P5

OR:

Wastewater Technology Centre,
Canada Centre for Inland Waters,
Environment Canada,
P. O. Box 5050,
Burlington, Ontario
L7R 4A6

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RR50	Anaerobic Digestion of Lime Sewage Sludge, S.A. Black, Ontario Ministry of the Environment, 1976, 17p.	33
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RR58	Aerobic Digestion of Organic Sludges Containing Inorganic Phosphorus Precipitates, Volume I, J. Ganczarczyk and M.F.D. Hamoda, University of Toronto, 1977, 81p.	39
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RR60	Land Disposal of Sewage Sludge, Volume IV, University of Guelph, 1977, 317P.	42
RR67	Chemical Sewage Sludge Disposal on Land (Lysimeter Studies), Volume I. V.K. Chawla, D.N. Bryant, D. Liu and D.P. Cohen, Environment Canada, 1977 98p.	44
RR69	Re-use of Waste S02 and Phosphate Sewage Sludges by Solidification with Lime and Fly Ash. Acres Consulting Services Limited, 1977, 22p.	45
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RR71	Development of an Efficient Sampling Strategy to characterize Digested Sludges. H.D. Monteith and J.P. Stephenson, Environment Canada. 1978, 124p.	48
RR72	Sludge Dewatering Design Manual. H.W. Campbell, R.J. Rush and R. Tew. Environment Canada. 1978, 133p.	50
RR73	Land Disposal of Sewage Sludge, Volume V. University of Guelph, 1978, 203p.	51
RR74	Sludge Incineration and Precipitant Recovery, Volume II, P.J.A. Fowlie and W.E. Stepko, Environment Canada, 1978, 35p.	53
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RR79	Chemical Sewage Disposal on Land (Lysimeter Studies) Volume II, D.P. Cohen and D.N. Bryant, Environment Canada, 1978, 128p.	57
RR80	Sources of Metals and Metal Levels in Municipal Wastewaters. E.D. Atkins and J.R. Hawley, Ontario Ministry of the Environment, 1978, 408p.	59
RR86	Nitrification - Denitrification of wastewater, Using a Single Sludge System, Volume I, A.G. Smith, Ontario Ministry of the Environment, 1978, 75p.	60
RR88	Single Sludge Nitrogen Removal Systems. P.M. Sutton, B.E. Frank and B.A. Monaghan, Environment Canada, and K.L. Murphy, McMaster University, 1978, 164p.	62
RR90	Land Disposal of Sewage Sludge, Volume VI. University of Guelph, 1979, 230 p.	63
RR91	Impact of Nitrilotriacetic Acid (NTA) on an Activated Sludge Plant - A Field Study, N. Wei, R. Stickney, P. Crescuolo and B.P. LeClair, Environment Canada, 37p.	65
RR96	Nitrification-Denitrification of Wastewater, using a Single Sludge System, Volume II. A.G. Smith, Ontario Ministry of the Environment, 67p.	66
RR98	Land Disposal of Sewage Sludge, Volume VII T.E. Bates, A. Haq and Y.K. Soon, University of Guelph, 17p.	67

RR107	Sludge Incineration and Precipitant Recovery, Volume IV: Pilot Scale Multiple Hearth Investigations. W.H. Schroeder, P.J. Crescuolo, H.W. Campbell and D.B. Cohen, Environment Canada, 51p.	68
RR108	Land Disposal of Sewage Sludge, Volume VIII. T.E. Bates amd Y.K. Soon, University of Guelph 17p.	69
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RR110	Parasites and the Land Application of Sewage Sludge. H.J. Graham, Ontario Ministry of the Environment, 84p.	71

CONFERENCE PROCEEDINGS NO. 2

SLUDGE HANDLING AND DISPOSAL SEMINAR

September 18-19, 1974

Toronto, Ontario

The disposal of sewage sludge onto agricultural lands under proper conditions is not only economical but can result in fertilization and improvement of soil properties. Recently, however, questions have arisen concerning the potential environmental problems associated with this method of disposal and the introduction of chemical sludges from phosphorus removal facilities has further complicated these questions. Studies are needed to fully understand and determine the nitrogen balance, and movement and fate of nitrogen compounds in soils, plants and water. The level of heavy metals in sludges is also of concern because of potential problems associated with build-up in soil, uptake by plants, effect on plant growth, runoff, pollution of groundwater and leaching after long-term build-up in soil. In addition, very little is known about the pathogenic aspects of sewage sludge disposal on land.

The sludge handling topics discussed at this seminar covered such subjects as: dewatering, filtration, centrifugation, incineration, metal removal or reclamation, trucking and pumping. Results of research projects funded under the Canada-Ontario Agreement on both sludge handling and disposal were discussed by approximately thirty authors and researchers.

Compilation of papers: 28

Total of 465 pages, illustrations, tables

LIST OF PAPERS PRESENTED

A Overview of Canadian Sludge Handling and Land Disposal - Practices and Research Needs in Canada
- S.A. Black, Ontario Ministry of the Environment and N.W. Schmidtke, Environment Canada 11p.

B Sludge Handling and Disposal Practices in England
- J. Webber, Ministry of Agriculture Fisheries and Food, U.K. 17p.

C Use of Sewage Sludge in Agriculture with Adequate Environmental Safeguards
- W.E. Larson, R.H. Susag, R.H. Dowdy, C.E. Clapp and R.E. Larson U.S. Department of Agriculture and University of Minnesota 14p

D Aerobic and Anaerobic Sludge Digestion Processes
- B.I. Boyko, Ontario Ministry of the Environment 23p.

E Biological Characteristics Digested Chemical Sewage Sludges
- V.C. Chawla, J.P. Stephenson and D. Liu, Environment Canada 31p.

F Virological Investigations on Sludges from Selected Ontario Sewage Plants
- T.P. Subrahymanyan, Ontario Ministry of Health 19p.

G Regulatory Aspects of Sludge Utilization on Land
- G.M. Wood, Ontario Ministry of the Environment 12p.

H Agricultural Use of Digested Sludges
- L.R. Webber and B.C. Hilliard, University of Guelph 24p.

I (i) Land Disposal of Sewage Sludge
- T.E. Bates, E.G, Beauchamp, J.W. Ketcheson, R.A. Johnston, R. Protz, J.R. Moyer, A. Haq and W. Curnoe, University of Guelph 6p.

I (ii) Effects of Sewage Sludge on Crop Growth and Nutrient and Metal Uptake
- T.E. Bates, J.R. Moyer and A. Haq, University of Guelph 9p.

J Nitrogen Transformation and Uptake
- E.G. Beauchamp and J. Moyer, University of Guelph 16p

K Run-off and Erosion Losses
- W.E. Curnoe, University of Guelph 11p.

M Cation Distribution in Soils
- R. Protz 2p.

N Disposal of Chemical Sludges on Land and their Effects on Plants, Leachate Quality and Soil Systems
- V.K. Chaula, D.N. Bryant and D. Liu 26p.

O Development of Analysis of Metals in Sewage Sludge and Liquids Associated with Sludges
- J.C. Van Loon, University of Toronto 18p

P Extractable Metals in Mixtures of Soils and Sewage Sludge
- M.D. Webber and J.D. Gaynor, Agriculture Canada 21p.

Q Chemical tests for Plant Available Metals in Soils
- T.E. Bates and A. Haq, University of Guelph 2p.

R Design information on Dewatering Properties of Wastewater Sludges
- J.D. Farrell, Environmental Protection Service 13p.

S Effects of Control Variables and Sludge Characteristics on the Performance of Dewatering and Thickening Devices
- H. Campbell and B.P. Le Clair, Environment Canada 35p.

T The Use of Physicochemical Sludge Characteristics and Bench Dewatering Tests in Predicting the Efficiency of Thickening and Dewatering Processes
- R. Stickney and B.P. Le Clair, Environment Canada 35p.

U Centrifuges - Types and Application
- F.W. Keith Jr., Penwalt Corporation 16p.

V Sludge Dewatering using the Kruger Centrifuge
- L.P. Roe, The East Asiatic Company (Canada) Ltd. 17p.

W The Vacuum Dewatering of Sewage Sludges
- G.D. Kemp, Komline - Sanderson Ltd. 8p.

X Aspects of Incinerating Chemical Sludges
- E.E. Shannon, D. Plummer and P.J.A. Fowlie, Environment Canada 22p.

Y Removal of Phosphates and Metals from Sewage
- D.S. Scott and H. Horlings, University of Waterloo 29p.

Z Sludge Handling and Disposal Practices in the Regional Municipality of Niagara
- E.R. Simonen, R.M. of Niagara 11p.

AA Sludge Handling and Disposal Practices in Metro Toronto
- W.A. Salib, Metropolitan Toronto, 11p.

SLUDGE UTILIZATION AND DISPOSAL SEMINAR
February 20-21, 1978

The Utilization of sewage sludge is carefully distinguished from the various methods of ultimate disposal. Problems, practices and trends arising in sludge utilization on agricultural land, including viruses parasites and heavy metals are reviewed. Sludge treatment options for disposal are presented and their costs are discussed.

Ontario's proposed guidelines for sewage sludge utilization on agricultural lands and procedures for obtaining approval for such applications are presented.

Compilation of Papers: 28
Total of illustrations, tables, papers: 471 p.

LIST OF PAPERS

1 PRACTICES AND TRENDS IN SEWAGE SLUDGE UTILIZATION AND DISPOSAL
S.A. Black, Ontario Ministry of the Environment and N.W. Schmidtke, Environment Canada. 30 p.

2 A METHODOLOGY FOR IMPROVED SLUDGE SAMPLING AND CHARACTERIZATION
J.P. Stephenson and H.D. Monteith, Environment Canada 30 p.

3 VIRUSES AND PARASITES IN SEWAGE SLUDGE
A.H. Vajdic, Ontario Ministry of the Environment 11 p.

4 METALS IN MUNICIPAL WASTE WATERS - SOURCES, LEVELS & CONTROLS
E. Sheridan, J.R. Hawley, Ontario Ministry of the Environment 12 p.

5 LAND DISPOSAL OF SEWAGE SLUDGE
T.E. Bates, E.G. Beauchamp, A. Haq, J.W. Ketcheson and Y.K. Soon University of Guelph and J.R. Moyer, Agriculture Canada 34 p.

6 LAND APPLICATION OF MUNICIPAL SEWAGE SLUDGE - LYSIMETER & FIELD STUDIES
D.B. Cohen, M. Webber and D.N. Bryant, Environment Canada 33 p.

7 GUIDELINES FOR SEWAGE SLUDGE UTILIZATION ON AGRICULTURAL LANDS
P. Seto and P. DeAngelis, Ontario Ministry of the Environment 30 p.

8 SLUDGE DISPOSAL PRACTICES AND OPTIONS FOR THE REGIONAL MUNICIPALITY OF WATERLOO
G.H. Thompson and D'Arcy B.G. Dutton, RM of Waterloo 26 p.

9 SLUDGE THICKENING, CONDITIONING AND DEWATERING FUNDAMENTALS
N.W. Schmidtke, Environment Canada 49 p.

10 DESIGN CONSIDERATIONS FOR SLUDGE THICKENING AND DEWATERING PROCESSES
H.W. Campbell, Environment Canada 41 p.

11 NET ENERGY REQUIREMENTS FOR SEWAGE SLUDGE INCINERATION
N.J. Perkins, Gore and Storrie Ltd., B. Wasmund, Hatch and Associates 18 p.

12 COMPOSTING OF SEWAGE SLUDGE BY MEANS OF FORCED AERATION AT WINDSOR, ONTARIO
J. Faust and L.S. Romano, City of Windsor 21 p.

13 UNITED STATES SLUDGE DISPOSAL REGULATIONS - IMPACTS UPON MUNICIPAL SEWAGE TREATMENT AGENCIES - COMPARISON WITH EXPERIMENTAL RESULTS
D.R. Zenz, J. Peterson and C. Lue-Hing, Metropolitan Sanitary District of Greater Chicago and T.D. Hinesly, University of Illinois 44 p.

14 COST ESTIMATION TECHNIQUES FOR SEWAGE SLUDGE DISPOSAL
D.R. Woods, S. Vijayan, S.L. Norman, S.J. Anderson, McMaster University and H. Campbell, Environment Canada 87 p.

15 GUIDELINES FOR APPLYING FOR APPROVAL FOR SLUDGE UTILIZATION ON LAND
J.R. McMurray, Ontario Ministry of the Environment 22 p.

LAND APPLICATION OF SEWAGE SLUDGE

T.E. Bates
Department of Land Resource Science
University of Guelph

This review was undertaken largely to determine where knowledge is lacking for ecologically safe and agriculturally productive application of sewage sludges to farm lands.

From this review it was concluded that sludge is quite variable in solids and nutrient content from one sewage plant to another and from day to day or week to week at any one plant. This is foreseen as a possible major problem in establishing safe rates of application.

Nitrogen is likely to affect safe rates of sludge application and rates should be restricted to those needed for crop production, at least until more information is available. Phosphorus pollution of the groundwater is not expected to be a major problem controlling application rates except on organic and sandy soils. Phosphorus could cause problems in surface drainage due to erosion and runoff.

The metals copper, zinc, cadmium, nickel, chromium and lead are high in some sludges and may be cause for concern. Other metals may also be of concern in particular sludges. Toxicities of copper and zinc to plants have caused problems in Britain and Europe. Cadmium is of concern for human health reasons and since this review was written it has also been reported to reduce plant growth at tissue levels as low as two parts per million. Soils absorb large quantities of most metals in forms unavailable to plants, provided there is a plentiful oxygen supply and provided the soil pH is maintained at a high level. It is suggested, however, that the best long-term method of controlling heavy metals may be to prevent them from reaching the sewage plant.

Studies are reported on the survival of human and animal pathogens and viruses in sludge. The populations appear to be reduced but not eliminated by anaerobic digestion. They are essentially eliminated by heat drying. Human and animal parasites, particularly ascaris, survive sludge digestion and may persist in and on the soil for considerable periods, survival time increasing with high clay and organic matter content.

No information was found concerning the land application of sludges resulting from treating sewage with chemicals for the removal of nutrients. Although major problems are not expected with these sludges resulting from the use of lime, aluminium sulphate and ferric chloride, research is needed.

There was little information found on times and methods of sludge applications which will not cause surface water contamination by erosion and runoff.

Research Report No. 3

AEROBIC DIGESTION OF ORGANIC SLUDGES CONTAINING INORGANIC PHOSPHORUS PRECIPITATES: PHASE I

J. Ganczarczyk and M.F.D. Hamoda

University of Toronto

Laboratory batch and semi-continuous experiments were carried out at 20°C on the aerobic digestion of activated sludges containing aluminum salts (precipitation with alum) or ferric salts (precipitation with ferric chloride) used for phosphorus elimination. Treatment responses measured were digested sludge characteristics (volatile solids destruction, oxygen uptake, settleability and dewaterability) and supernatant characteristics (soluble total organic carbon, soluble nutrients and suspended solids). The only variable that was controlled for all experiments was the sludge hydraulic detention time.

Series I of experiments comprised 3 batch aeration tests which lasted 28 days and were carried out using sludges precipitated with alum (200 mg/l) or ferric chloride (10 mg/l as Fe^{+3}) and a control sludge. Series II covered 3 batch aeration tests that lasted for 21 days to treat sludges precipitated with alum (550 mg/l) or ferric chloride (30 mg/l as Fe^{+3}) and a control sludge. In Series III, aerobic digestion of the above 4 types of chemical sludges as well as a control sludge was carried out in both batch units (10 day aeration) and semi-continuous units (10 day theoretical detention time). The semi-continuous units were operated at average loadings of 0.06 lb VS/day/cu ft (960 g VS/day/cu m).

The performance of aerobic digestion of conventional activated sludges was not affected to any practical degree by the presence of ferric or aluminum precipitates. Release of soluble organic carbon and nutrients during the aerobic digestion of activated sludges was not enhanced in the presence of the chemical precipitates. Digested sludges showed poor dewatering characteristics especially when long aeration periods were employed in batch treatment.

An aeration period of 10 to 15 days appears to be adequate for obtaining satisfactory stabilized sludges. Under the conditions studied, batch operation of aerobic digesters resulted in a greater destruction of sludge volatile solids and a greater reduction in the sludge oxygen uptake rates than the semi-continuous operation. However, the latter method of digester operation provided sludges of better dewaterability and supernatant quality.

KEYWORDS: aerobic sludge digestion, chemical sludges, volatile solids destruction, sludge oxygen uptake rates, secondary growth, carbon and nutrients release, nitrification, digested sludge characteristics, batch and semi-continuous operation

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES: VOLUME I

J. C. Van Loon
University of Toronto

The disposal of sewage treatment plant sludges poses a serious problem. Potentially, these materials could be used as fertilizers on agricultural lands. This would be a double benefit acting as a disposal mechanism as well as a source of plant nutrients. On the other hand, a variety of reports have appeared urging caution in this regard for fear of contamination of the land by other matrix constituents. Among these are the potentially toxic heavy metals.

A series of reports, most of which have appeared in the past year, describe the metal content of domestic sewage plant sludges and sewage sludge fertilizers. A selection of references is given at the end of this report.

Researchers in several countries are presently developing projects designed to study the uptake by plants of heavy metals from sludged or otherwise metal contaminated soils. References on this subject also appear at the end of this report.

Despite a good deal of activity in this subject area, it is clear, from the references available to date, that very little data exist which reliably describe plant-metal interactions. Perhaps the most serious omission is that little attempt has been made in these papers to provide data on precision and accuracy of results.

The present study emphasizes the utilization of standard and control samples as tools for validating the data obtained. Because of the shortness of the investigation period no attempt was made to use statistical testing to provide a means for arriving at conclusions. It would seem too early to justify anything but a few generalizations.

Appendix I of this report lists additional references not cited in the text which may be of use to interested readers.

WET AIR OXIDATION OF CHEMICAL SLUDGES

R.R. Hudgins and P.L. Silveston
Department of Chemical Engineering
University of Waterloo

A study was made of the wet air oxidation of eight Ontario sludges containing phosphorus. Some of these sludges were obtained from primary or secondary clarifiers in which lime, ferric chloride, or alum had been used to precipitate phosphorus. Sludges were oxidized at temperatures up to 550°F (288°C) in a rocking autoclave, while total carbon and total organic carbon values were measured in samples withdrawn during oxidation. Selected total phosphorus and orthophosphorus analyses were made on both chemical and non-chemical sludges. Oxidation of the sludges was readily obtained. Wet air oxidation of chemical sludges appeared to reverse, to a limited extent, the stabilization of phosphorus achieved by prior chemical treatment. For non-chemical sludges, however, this was not always the case.

Further studies are recommended to explore the kinetics of wet air oxidation of chemical and non-chemical sludges.

Research Report No. 16

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME I

UNIVERSITY OF GULEPH

This study was designed as the first part of a three to five year project to determine the rates at which chemically treated sewage sludges may be safely applied to agricultural land.

Initial experiments with sludges resulting from sewage treated with lime, aluminum sulphate and ferric chloride are described in this report. The sludges were applied to three different soils at rates based on the total nitrogen content of each sludge.

The following aspects of sludge application to soil were investigated: rate of nitrogen transformation to soluble forms when chemical sludges were incorporated into sand-soil mixtures; bacterial contamination of runoff and groundwater; the macromorphology, micromorphology, and the chemical and physical states of the soil prior to application; the effect of sludges on plant growth; and, nutrient and heavy metal uptake by plants.

EVALUATION OF THE BARBER R. COLMAN WETOX PROCESS FOR SEWAGE SLUDGE DISPOSAL

P. Seto and D. K. Smith
Ontario Research Foundation

An investigation was carried out to evaluate the suitability of the Barber-Colman Wetox process for municipal sewage sludge disposal. Technical and economic data for the Wetox process were gathered through literature, special correspondence, pilot plant visits as well as some experimental and analytical work performed at the Ontario Research Foundation (ORF) laboratory. These Wetox data were then analysed and compared with those of other sludge disposal methods. Particular emphasis was placed on the comparison between the Wetox process and the Zimpro process since they are rather similar in operation.

Based on the evaluation of a limited amount of laboratory and pilot plant data, it appears that the Wetox process is simple to operate at 450°F, 600 psi (∿ 232°C, 4137 kPa) with 0.3% sulphuric acid. The process is suitable for sewage sludge disposal, although no commercial scale Wetox plant has yet been built. Furthermore, Wetox can achieve similar sludge destruction efficiency, i.e. approximately 80% destruction of suspended solids and 65-82% reduction in COD, but at a lower temperature and pressure than the corresponding Zimpro process. This is believed to be due to the design of the Wetox reactor, which ensures adequate oxygen transfer into the sludge, as well as the addition of a small amount of sulphuric acid to speed up the oxidation.

For larger scale sludge disposal (e.g. 100 tons or ∿ 91 metric tons dry solids per day), the total disposal cost (i.e. from digested sludge to ultimate land disposal), on per ton dry solids basis, via the Wetox process can be as low as $21 (∿ $23 per metric ton) if the plant is run under the most favourable conditions at full capacity. Realizing that only the major expenditure items are included in the cost estimates and other "hidden" costs may exist, the estimated cost of $21 is judged to be only approximate and probably low. Nevertheless, it does put the cost of the Wetox process into perspective. By comparison, the sludge disposal cost via the Wetox is substantially lower than via the high temperature-pressure Zimpro process. The Wetox cost is at least competitive with the low temperature-pressure Zimpro route as well as with other more conventional sludge disposal processes.

It is also noted that the Wetox process may have high potential for sludge disposal in small communities where land spreading is unsuitable.

Because only a limited amount of laboratory and pilot plant Wetox data are available, the aforementioned conclusions should be viewed as tentative until they can be verified with data obtained by further experimentation.

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME II

Department of Land Resource Science and Microbiology
University of Guelph

This report covers work done by the Departments of Land Resource Science and Microbiology at the University of Guelph on land disposal of sewage sludge under the Canada-Ontario Agreement on Great Lakes Water Quality and covers the period from April 1, 1973 to March 31, 1974

The report covers runoff studies with Fall, Winter and Spring applied sewage sludge, field rate and source of sludge studies with bromegrass on a loam soil and with corn on a loam, a sandy loam and a clay loam soil A greenhouse trial with different rates and sources of sludge on two soils at three pH levels is also reported. Fluid digested sewage sludges were used which came from calcium oxide treatment of Newmarket sewage, aluminum sulphate treatment of Point Edward sewage and ferric chloride treatment of North Toronto sewage. Chemical analyses of the sludges, soil nitrogen, crop yields and nutrient and metal content of crops are presented along with microbial studies of the sludges and the crops grown Detailed descriptions of the soils used are also presented.

In runoff studies high rates of sludge greatly increased nutrient loss from sloping land but metal losses were small with the sludges and rates used in this study.

In general, there was some crop growth response to the sewage sludges but in two trials a smaller response to the aluminum sludge from Point Edward was observed than to the others. Nitrification studies and plant nutrient analyses lead one to believe that the aluminum sludge has provided less available nitrogen to the crops than the other sludges but this does not fully explain the poorer growth with aluminum sludge. This effect of Al sludge does not appear to be related to difference in uptake of nutrients or metals other than nitrogen.

Sludges resulted in increased concentrations of copper and zinc in crops but not of other metals. There was little change in boron concentration.

Bacterial studies have, in general, not demonstrated increased populations of indicator organisms on plants or runoff water from sludge treated soils.

Differences in uniformity of chemical composition of sludges from the three sewage plants is discussed.

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES: VOLUME II

J. C. Van Loon
University of Toronto

In the previous year of this contract (1) studies were initiated in the following areas:

(1) Sludge heavy metal characterization of North Toronto, Newmarket and Point Edward sewage treatment plants.

(2) Heavy metal contamination of farm soils and vegetation resulting from sludge applications (Newmarket area).

(3) Surface water, heavy metal contamination resulting from sludge disposal.

(4) Assessment of analytical data.

During the present year, work was continued in all these subject areas. Heavy metal contamination studies of soils, vegetation, groundwater and surface water were carried out at the Burlington Skyway plant disposal farm and the North Toronto plant disposal area. A study of garden vegetable contamination due to the use of sludge for home gardening was also initiated.

Again as in the previous year emphasis was placed on using standard reference materials to give validity to the analytical data.

EXAMINATION OF SEWAGE AND SEWAGE SLUDGE FOR ENTEROVIRUSES: VOLUME I

ONTARIO MINISTRY OF HEALTH

A promising and practical method for taking advantage of the nutrient qualities of sewage sludge is to spread it on agricultural or grass land in rural areas. This method, however, carries an inherent risk that the environment may be polluted further with harmful agents such as viruses and heavy metals. This report deals with the first phase of a virus monitoring programme being carried out in the Enterovirus Laboratory of the Ontario Ministry of Health, Laboratory Services Branch, in connection with the plans to spread urban sewage sludge on rural land in Ontario.

The results of this programme include virus surveillance studies on five Ontario plants which employ different phosphate removal techniques, as well as related laboratory studies.

Gauze pad collections of sewage samples or sludge samples, collected in 100 ml volumes soon after mixing tank contents, were transported to the laboratory without delay. The specimens were extracted with alkaline Earle's balanced salt solution (pH 9.5) and the extract decontaminated by chloroform treatment. The aqueous layer, freed of residual chloroform, was tested for viruses in primary and continuous cultures of monkey kidney and human diploid fetal lung (WI-38) cells at least three times and the presence of virus demonstrated by cytopathic effects and electron microscopy as well as haemadsorption and interference testing. Any isolate was identified with pools of specific antisera to enteroviruses. In the case of poliovirus isolates, genetic marker and antigenic differentiation tests to distinguish between vaccine and virulent strains are in progress.

In preliminary experiments, it was established that chloroform treatment was an efficient means of removing extraneous microorganisms and that it had no effect on enterovirus viability. It was also found that virus extraction from sludge was maximal at pH 9.5, if the materials were well homogenized. The preliminary results also showed that 30 - 100% of added poliovirus could be recovered and that amounts as small as 1 $TCID_{50}$ per 0.1 ml could be detected.

During April, 1973 - December, 1974, a total of 900 specimens including 438 sewage specimens, 398 raw and digested sludge specimens and 64 specimens of water were investigated. Out of the 444 specimens tested in 1973, 40% of the sewage specimens (48/124) contained viruses although the collection period included several cold months during which enteroviruses were not detected in the community. Virus isolation rates in 1974 were lower, reflecting the generally lower isolation rates from clinical cases as well. Viruses from sewage included several poliovirus isolates. All the polioviruses are being carefully investigated to establish whether they are of vaccine origin or are virulent strains. Preliminary results indicate that at least one strain is definitely not related to vaccines and that perhaps a few others are intermediate in character, indicating that they too could be of non-vaccine origin. All the non-polio enteroviruses in this study are well known human pathogens and, therefore, it is important to ensure that they are inactivated before sludge is spread on soil. One important lacuna in this and similar studies is the present non-availability of a suitable test for the detection of hepatitis virus, but this gap may soon be filled. Until this becomes practical, all conclusions have to be necessarily of a guarded nature.

The most profitable lines of action that could be recommended would appear to be. (a) to intensify the surveillance studies so that the conclusions of the first year can be confirmed; (b) to develop practical methods for the laboratory detection of hepatitis viruses; and, (c) to take necessary steps to set up safety standards.

REMOVAL OF PHOSPHATES AND METALS FROM SEWAGE SLUDGES

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Most of the metals and phosphorus in either unconditioned or conditioned final anaerobically digested sludges can be readily extracted by acid. The acid extract can be neutralized under controlled conditions of pH to yield a solid product low in organic material containing mostly iron and aluminum phosphates. By proper control of pH, it is possible to produce two solid products, one containing most of the iron and aluminum, and one containing most of the heavy metals.

Iron and phosphate can be separated and recovered from the crude inorganic product by known solvent extraction technology, or by alkali treatment. Costs are such that if metals and phosphates are removed from a sludge, then it is profitable to recover and recycle the iron and phosphate from the crude inorganic product. However, the value of recovered metals and phosphates is not sufficient to bear the cost of the entire process.

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUDGES: VOLUME III

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This report describes existing and newly developed methods for the analysis of metals in sewage sludges. Atomic absorption and electrochemical techniques are emphasized. Procedures developed specifically for arsenic, selenium, mercury, tin and molybdenum analyses are included.

The quartz "T" tube furnace for flameless atomic absorption studies of thermal volatility and gas chromatography of metal compounds in sludge has been developed and is described.

A number of chemical sewage sludges were analysed for metals and the results are tabulated.

SLUDGE INCINERATION AND PRECIPITANT RECOVERY: VOLUME I

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Incineration has been a popular method of ultimate disposal of sewage sludges for many years. With the recent implementation of chemical phosphorus removal programs at municipal wastewater treatment plants, interest has developed in the recovery and recycle of the chemical precipitants (alum, iron, and lime) from incinerated sludge ash.

The Wastewater Technology Centre of the Environmental Protection Service initiated a "Sludge Incineration and Precipitant Recovery Program" in 1972. An extensive review of the related significant English language literature from the period 1968 to 1974 was performed as part of this program and is summarized in this bibliography.

THE REMOVAL AND RECOVERY OF METALS FROM SLUDGE AND SLUDGE INCINERATION ASH

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The electrochemical plating of Cu, Zn, Ni and Cd from aqueous solutions has been studied using standard plate type electrodes and improved efficiencies were attained with fluidized bed electrodes. Because direct electroplating from sludge was found to be inefficient, acid and base additions were made to solubilize the metals prior to plating.

Most of the metals and phosphorus in the digested sludge could be dissolved by adding sufficient H_2SO_4 or HCl to lower the sludge pH to 1.5. The average cost of acid required per ton of dry solids was $41 for the H_2SO_4 and $77 for HCl. Little economic advantage would be gained by recovering sludge constituents, since processing costs for the large volumes of dilute leachate would be high. Therefore, the removal of heavy metals from wet sludge to reduce their toxicity does not appear to be economically feasible.

The metals and phosphorus in sludge incinerator ash can be solubilized with H_2SO_4 in a countercurrent stepwise process which uses most of the acid. Further processing of the H_2SO_4 leachate for recovery of valuable constituents is complicated by the presence of large quantities of iron in the leachate. Neutralization of the leachate with NaOH precipitates all the metals and phosphorus. Treating this precipitate with a hot NH_4OH - $(NH_4)_2SO_4$ mixture resolubilizes most of the trace metals and phosphorus leaving iron oxide in the solid phase. Electroplating can remove Cu, Zn, Ni and Cd from the ammonia leach, and ammonium phosphate can be recovered from the solution after electrolysis. While processing costs for incinerator ash are much less that those for wet sludge, the procedure does not appear to be economically viable except for very large treatment plants.

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME III

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This report covers runoff studies with fall, winter and spring applied sewage sludge, and field rate and source of sludge studies with bromegrass on a loam soil and with corn on a loam, a sandy loam and a clay loam soil. A greenhouse trial with different rates and sources of sludge on two soils at three pH levels is also reported. Fluid digested sewage sludges from calcium oxide treatment of Newmarket sewage, aluminum sulphate treatment of Kitchener sewage and ferric chloride treatment of North Toronto sewage were used. Chemical analyses of the sludge, soil nitrogen, crop yields and nutrient and metal content of crops are presented along with microbial studies of the sludge and the crops grown. Detailed descriptions of the soils used are also presented.

In runoff studies, losses of nitrogen and nutrients were low in 1974, lower than 1973. One runoff event immediately following fall sludge application resulted in appreciable losses of nutrients, metals and COD.

In the field, crops responded to sewage sludge, responses being similar in most cases to those from chemical fertilizers. In one trial, where soil structure was a problem, sludges produced appreciably higher yields than chemical fertilizers. In the greenhouse, sludge at high rates of application caused salinity problems when the soils were not leached. Salinity is not expected to cause problems in the field in Ontario.

About twice as much nitrogen was required from sludges as from ammonium nitrate to produce a particular yield. At higher rates of sludge application, levels of nitrate toxic to animals were approached.

Sludges increased sodium bicarbonate soluble ("plant available") phosphorus quite markedly, and this effect was greatest with calcium sludge.

Cadmium, nickel and zinc concentrations in crops increased appreciably with additions of sludge high in metals. Greenhouse studies provide some evidence that these metals become more available to plants with time after sludge applications.

Chemical soil tests for plant available metals are under investigation. At this time, acetic acid appears to hold promise as an extractant of nickel under Ontario conditions.

In field soils, nitrate accumulated to a greater extent under corn than under grass. More nitrate was produced by sludges containing a larger portion of their nitrogen in ammonium form. Nitrate concentrations in soil were high in 1974 with less evidence of movement than in 1973, probably due to the lower rainfall in July and August.

Extraction, electron microprobe and X-ray analyses show that the iron in iron sludge is crystalline. Where sludges nave been applied to the soil surface, calcium, aluminum and iron all appear to be moving into the soil, but calcium moved the farthest, up to 12 inches in two years.

COMPUTER-AIDED PLANNING OF REGIONAL SLUDGE DISPOSAL SYSTEMS

B. and P. Silveston, Engineers, and
Canadian Federation of Mayors and Municipalities

This manual is intended to serve a number of purposes. First of all, it is a training manual which introduces potential users to the concepts of computer-aided planning, the models for sludge disposal that are imbedded in the computer programs, and the information which must be developed in order to use the programs. The manual is also a source book for setting up a data collection program to be used with computer-aided planning. It contains the coding which transforms the data into the proper form for processing by a computer. Thirdly, the manual provides detailed information on the structure of the computer program, so that it can be modified for special purposes or expanded to handle different planning problems such as refuse disposal. Only a minor attempt has been made to indicate the chronology of the project, the sources of information used and the problems tackled during its active life. In a very real sense, the User's Manual is the final product of work undertaken in the project.

A general purpose computer program applicable to the optimizatio of regional sludge disposal systems is described. The model upon which the computer program is built is a network of transport routes connecting nodes which represent sources of sewage sludge, intermediate facilities for processing or the temporary storage of sludge (such as vacuum filters or lagoons), and dead-end facilities for ultimate disposal (such as landfill or land spreading sites). Since the spreading of sludge on land is an alternative which will usually be considered, and as this is permitted only within certain portions of the year, the model permits intermediate facilities to be designated for winter storage of sludge which would otherwise be distributed to dead-end facilities which are seasonally restricted.

The engineer-planner within the computer-aided method retains his essential position, but the nature of the work he does is changed by the technique. In addition to data collection, it is his responsibility to postulate sets of facilities (without specifying their size, but only the upper limits on size) which are to be considered within the computer program. Using given transport costs per unit volume of sludge (as functions

of travel time) and given functions of facility cost versus size, which must also be supplied by the engineer-planner, the computer program finds what combinations of facilities meet the disposal requirements at least cost and how sludge should be distributed from the sources to these facilities. The computer program actually prints out lists of the near optimal solutions to the planning problem. It then becomes the responsibility of the engineer-planner to analyse these solutions and develop, through the use of case studies, a solution which gives low cost sludge disposal and also satisfies aesthetic social and political considerations as well.

To test the performance of the computer program, the Regional Municipality of Niagara supplied cost data, lists of potential disposal facilities and their locations, and data on sludge productions at the various waste treatment plants located within their boundaries. A detailed study of sludge disposal in the Regional Municipality was not undertaken; however, runs were made to examine the sensitivity of the computer generated solutions to assumptions in the cost data. Runs were made also for projected sludge production in 1980 and 1990. This yielded a picture of the development of the sludge disposal system with time. It is perhaps this aspect which may be most valuable to the engineer-planner, since long term studies are hardly conceivable without computer assistance.

A second computer program was developed in the course of this project to plan an optimal transport system to move from sludge to sources to the chosen disposal facilities. Given depot locations for the trucking fleet, the carrying capacity of trucks, and an operating factor, the computer program generates the least cost schedule of pickups for the sludge disposal network. Allowing depot locations and truck sizes to vary, a case study approach can be used to find an optimal transport system for sludge. Conditions of this contract only permitted development of the basic computer program for this task. Although this program has been tested on a hypothetical example, application to a real system will probably be necessary before it can be released for general use. Some polishing of the program to simplify data input and improve the computer printout is also required.

ANAEROBIC DIGESTION OF LIME SEWAGE SLUDGE

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This study, designed to assess the ability of the anaerobic digestion process to accept the sludge produced by the addition of hydrated lime to the raw sewage of a conventional activated sludge plant, was supported under the Canada-Ontario Agreement on Great Lakes Quality.

The study was carried out in conjunction with full-scale phosphorus removal at the Newmarket 2.0 MIGD activated sludge plant. This report covers an intensive sampling program on the two-stage anaerobic digester carried out between March, 1972 and March, 1973.

The study determined that normal digester operation when receiving lime sewage sludge may be anticipated, but that care should be used to eliminate shock loading effects when starting up a digester on lime sewage sludge.

HEAVY METALS IN AGRICULTURAL LANDS RECEIVING CHEMICAL SEWAGE SLUGES: VOLUME IV

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This report reviews existing and newly developed analytical methods for sewage sludge analysis. It had been stressed earlier that knowledge of the form of metals in waste and environmental samples is of great importance. As a result of this the development of simple equipment and analytical methods to initiate metal speciation has been stressed.

Procedures developed earlier and used provisionally have been studied in depth. The mercury method is now acceptable as recorded. The As/Se procedure has been modified as a result of further investigation. Nonflame atomic absorption methods have been developed for silver and vanadium.

It is demonstrated that using atomic absorption spectroscopy as a detector does not guarantee a quick solution to metal speciation problems.

Sludges can be dry-ashed at 450°C without fear of loss of cadmium, lead or appreciable amounts of zinc. When aluminum is to be determined, dry-ashing should not be used. Data also make it clear that incineration at temperatures usually employed will release large amounts of arsenic, cadmium, lead, mercury and zinc.

A number of sewage sludges were analyzed, and the results are tabulated.

EXAMINATION OF SEWAGE AND SEWAGE SLUDGE FOR ENTEROVIRUS VOLUME II

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Spreading of sewage sludge on agricultural or grassland in rural areas carries an inherent risk of polluting the environment with harmful viruses and heavy metals contained in the sewage. Monitoring of sludge for viruses is, therefore, one important aspect of sewage disposal; first, to determine the extent of the problem, and second to ascertain the efficiency of present treatment methods in virus removal. This report deals with the first phase of the program at the Enterovirus Laboratory, Ontario Ministry of Health, Laboratory Services Branch, relating to spreading urban sewage sludge on rural land in Ontario.

Results include virus surveillance studies at five plants using different phosphate removal techniques, and related laboratory studies. The plants involved were the North Toronto pollution control plant, and the treatment plants at Lakeview, Newmarket, Point Edward and Sarnia. Plants at Brampton, Burlington and the other Metro Toronto plants were included for comparison.

During April 1973 - December 1975, a total of 1317 specimens, including 642 sewage specimens, 540 raw and digested sludge specimens and 135 specimens of water were investigated. Out of the 444 specimens tested in 1973, 40% of the sewage specimens (48/124) contained virus, although the collection period included several cold months during which enteroviruses were not detected in the community. Virus isolation rates in 1974 and 1975 were lower, which paralled the lower isolation rates from clinical cases as well. The virus isolates from sewage included several poliovirus isolates. Preliminary results indicate that at least one strain is definitely not derived from vaccine; a few others are intermediate in character, indicating that they too could be of nonvaccine origin. All the nonpolio enteroviruses found in this study are well-known human pathogens and, therefore, it is important to ensure that they are inactivated before sludge is spread on soil. One important shortcoming of this and similar studies is the present nonavailability of a suitable test for the detection of hepatitis and gastroenteritis viruses. Until this is resolved, the real risk of viral contamination cannot be accurately assessed. Thus, our conclusions have to be considered provisional.

In the present study several enteroviruses persisted in sludge many weeks. This also agrees with limited experience in the field. Sludge utilization programs should take into account the possible presence of pathogenic viruses in sludge and the potential for an extended health hazard. The presence of the more easily inactivated reoviruses in sludge suggests that the more virulent enteric viruses were not found only because they were not circulating widely in the community.

LAND APPLICATION OF DIGESTED SEWAGE SLUDGE UNDER ADVERSE CONDITIONS

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This study involved the disposal of sludge on land which, because of continual periods of rain or spring melting conditions, had become impassable to normal sludge hauling vehicles (tank trucks). The reasons for this concern were:

(1) the deterioration of the sewage treatment plant effluent quality if sludge removal cannot be carried out for an extended period, and

(2) the cost of sludge holding facilities in adverse conditions.

Initially, two separate literature reviews were conducted:

(1) The first was made to determine current equipment used in sludge application to land and to assess potential problems associated with the equipment to be tested. Little written information was available on this topic and it was necessary to obtain data by personal communication.

(2) Agricultural literature on soil compaction was reviewed to determine the effects of vehicular traffic on soil.

Five vehicles (a tank truck, a sludge injector, a bulldozer, a front-end loader and an all-terrain vehicle) were field tested and evaluated. The tank truck was used as a control vehicle; the bulldozer and front-end loader were tested because of their availability rather than any inherent qualities which lend themselves to sludge spreading; the sludge injector and all-terrain vehicle had been used with a great deal of success previously for sludge disposal on land. A system for sludge spraying was also investigated.

Soil compaction analyses, crop analyses, problems experienced, and breakdowns encountered during spreading were used as parameters for evaluation. None of the vehicles investigated proved ideally suitable and effective in the spreading of sludge on wet soils.

Spraying of sludge proved to be the most suitable method for land application under certain weather conditions but was suitable only for well-screened sludge. The sludge injector was judged as the vehicle which caused minimal field damage in terms of compaction under the wheels

and, therefore, most appropriate for land disposal of sludge where ploughing was to follow the application on forage or fallow crops. However, it left deep ruts in the clay soil, where the injector device failed to properly refill the furrows and showed a number of operational problems. While in operation, the ploughing apparatus frequently plugged up with sod and dirt, making it necessary to stop the operation and clear the obstructions. The sludge injector system was also prone to mi[illegible]ng and was ineffectual in hard or frozen ground.

AEROBIC DIGESTION OF ORGANIC SLUDGES CONTAINING INORGANIC PHOSPHORUS PRECIPITATES

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Lime treatment of raw sewage for phosphorus removal and/or for better clarification has been recently implemented in many wastewater treatment plants. However, aerobic digestion of the sludges that result from treatment has not yet been studied.

Laboratory experiments were carried out at 20°C in completely mixed digestion units on sludges collected from a municipal wastewater treatment plant in Metropolitan Toronto. Tests were carried out simultaneously on lime-primary sludges (precipitated with $Ca(OH)_2$) and primary sludges (no chemical addition). Batch digestion experiments and semi-continuous (fed once a day) loading experiments were carried out. Lime-primary sludges from raw sewage precipitated with different lime dosages (140-600 mg/l) were studied at pH values in the range of 9-12. For comparative purposes, all sludges studied had initially a similar volatile solids content. Digester detention time was varied from 7 to 15 days to investigate the effect of this parameter on aerobic digestion of the sludges.

It was found that aerobic digestion of lime-primary sludges was feasible, but aeration periods of at least 15 days at 20°C were required for effective treatment, especially for sludges having an initial pH in the higher range of values. The digestion process kinetics of lime-primary sludges with initial pH in the range of 9-10 were higher than those of the primary sludge (control) but for lime-primary sludges having initial pH in the range of 10-12, the high alkalinity or calcium content of the sludge resulted in lower process kinetics. The nitrification process was inhibited in digesters treating sludges precipitated with high lime dosages. The supernatant of the digested sludges had low soluble organic carbon and nutrient (phosphorus and nitrogen) contents. The aerobically digested lime-primary sludges had excellent dewatering characteristics.

FULL SCALE STUDIES ON THE THERMOPHILIC ANAEROBIC DIGESTION PROCESS

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A plant scale thermophilic anaerobic digestion study was conducted to assess the feasibility and performance and to provide economic guidelines for the process as compared with the conventional mesophilic system.

The study was conducted in four distinct phases; the first three at specific applied digester loadings, with the fourth and final phase studying the effect of shock loadings. A full scale mesophilic digestion system, operating on the same raw sludge feed, was used as a comparison.

The study proved full scale thermophilic digestion to be feasible and capable of sludge stabilization performance similar to the mesophilic control unit, but at more rigorous applied digester loading levels.

At equal digester loadings of 0.08 lb VS/ft^3/day (1.3 kg/m^3·d) and retention times of approximately 25 days, the thermophilic and mesophilic units achieved similar overall volatile solids reductions of approximately 40%. The thermophilic system produced slightly more gas and greater microorganism destruction than the mesophilic control system, but the thermophilic digested sludge dewatering characteristics and supernatant liquor solids were inferior.

In the second and third phases of the study, at digester loadings of 0.14 and 0.20 lb VS/ft^3/day (2.2 - 3.2 kg/m^3·d), respectively, and associated sludge retention times of 15 and 7.5 days, the thermophilic unit continued to provide good overall solids reductions of approximately 40%. The related gas production rates were similar to those achieved in the control unit. The latter was operated at a constant loading of approximately 0.08 lb VS/ft^3/day (1.3 kg/m^3·d) as it was not feasible to increase raw sludge feed rates. Digested sludge chemical, physical and bacteriological characteristics at the higher loadings were little changed from those seen during the first phase of the study.

The operating parameters of the two systems were similar, with the exception that the thermophilic primary digester pH and volatile acids levels were higher than those seen in the control unit, averaging 7.4 and 2600 mg/l respectively as opposed to 7.0 and 95 mg/l.

The quality of the gas from both systems was similar, averaging 65% methane, with the balance being carbon dioxide. In the thermophilic process, the gas quality remained constant throughout the range of applied digester loadings studied.

The final phase of the study showed that widely and frequently varying applied digester loadings had little effect upon the thermophilic process, which proved to be very flexible in producing a good all round performance under the range of shock loadings applied.

While no actual operating cost comparison was made between the two digestion systems, estimates of energy requirements based on the data obtained showed that requirements would be slightly greater for the thermophilic process. However, the magnitude of the increase was such that conversion of existing overloaded mesophilic systems to thermophilic operation would be feasible and acceptable in view of the likely benefits to be obtained.

Research Report No. 60

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME IV

T.E. Bates, E.G. Beauchamp, R.A. Johnston
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This report discusses the results from the third year of field runoff studies with fall, winter and spring applications of fluid sewage sludge on land cropped with grain corn Runoff of water, soil, nutrients and metals were measured. The report also covers field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride, and aluminum sulphate for phosphorus removal. One experiment involves surface sludge applications on a loam soil on which bromegrass is grown, and three trials involve corn on a loam, a sandy loam and a clay loam soil. In one greenhouse experiment, nine fluid sewage sludges, selected for their high metal content, were applied to a soil previously adjusted to two pH levels. Five crops of ryegrass were grown with sludges added to the soils before each crop. Crops growth, and nutrient and metal uptake were studied along with micropedological studies of the soils. The sludges and field-grown crops were monitored for pathogenic organisms. Field experiments and laboratory studies were used to estimate the nitrogen availability from sludge and the rates of volatilization of nitrogen from surface applied sludge in the field. A greenhouse experiment was also run on a group of soils varying in metal content. The soils were extracted with various chemicals in an effort to find suitable extractants for plant available cadmium, copper, nickel, lead and zinc.

Total runoff in 1975 was similar to 1973 and 1974, as were nitrogen, phosphorus and metal losses. Metal losses were small and mostly associated with summer losses of soil solids. Runoff from a 6% slope was similar to that from a 2% slope in winter but greater in summer. Sludge application had no effect on total runoff volume.

In the field rate and source studies the bromegrass had slightly higher yield with sludge than with ammonium nitrate. At low rates of application the calcium sludge tended to produce lower yields and higher yields at higher rates of application than the other sludges, a trend which was apparent in 1974.

The sludges markedly increased sodium bicarbone-extractable, "plant available" soil phosphorus, with the calcium sludge being much

more effective than the other sludges. Phosphorus concentrations in the crops were high and unaffected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application, the effect being greatest with the sludge supplying the most cadmium. Nickel, chromium and copper were increased in some plant tissues at some sites, but the effects were not consistent. Zinc concentration increased in bromegrass, corn grain, and at one site in corn stover. Molybdenum in plant tissue appeared to increase with sludge application.

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next (up to the fifth crop) at any of the rates studied. One application of sludge resulted in nickel concentrations in the first three crops of ryegrass that were as high as in treatments receiving three applications of the same amount of sludge. Cadmium, copper and zinc showed slightly reduced concentrations in later crops of ryegrass where sludge was applied only once.

As in previous years, NH_4^+-N applied in sludge was rapidly transformed to NO_3^- in the soil in the field. Leaching of NO_3^- was apparently greater during the fall in the sandy loam soil than in the other finer textured soils. There was some evidence of release of NO_3^- from sludge applied to the clay loam in the previous two years. Sludge applications had little influence on NH_4^+ and pH levels in the soils, with the exception of calcium sludge which significantly increased pH. The concentration of NO_3^--N in the soil solution generally exceeded the accepted level of 10 µg NO_3^--N/ml, particularly where larger quantities of sludge were applied.

Chemical treatment of sludges had no apparent effect on NO_3^- production from sludges mixed in soil. However, sludge from Point Edward resulted in relatively slow NO_3^- production, suggesting an inhibitory substance present in the sludge. Approximately two-thirds of the organic nitrogen fraction of sludges was mineralized during a 49-day incubation period in the laboratory.

Research Report No. 67

CHEMICAL SEWAGE SLUDGE DISPOSAL ON LAND (LYSIMETER STUDIES) VOLUME I

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Environment Canada

A lysimeter project using two typical Ontario agricultural soils was initiated in October, 1972 at the Wastewater Technology Centre, Burlington. The experiment was designed as a randomized block of 22 treatments (11 fertility treatments to each soil). These 22 treatments were replicated three times for a total of 66 lysimeters. The 11 fertility treatments consisted of three chemical sludge types (alum, iron and lime) each at three application rates, plus two controls (with and without NPK fertilizer). Cumulative sludge application rates at the end of 1974 were 700, 1400, and 2100 kg TKN/ha.

Orchard grass was planted in the lysimeters in May, 1973 with subsequent grass harvests monitored for total dry matter yield, plant tissue chemical concentrations and uptakes. Leachate volumes, chemical constituents, and losses were determined, as were microbial concentrations in sludge, leachate, and soil. Chemical constituent material balances were calculated for each treatment.

Increasing rates of sludge application up to a cumulative loading of 2100 kg TKN/ha produced increased yields. The highest grass yields in both 1973 and 1974 were obtained from the iron sludge at the highest application rate. Potassium concentrations in plants grown in 1974 on loamy sand were deficient (<1.0% K) at the higher sludge loading rates. Concentrations of N, P, Ca, and Mg were adequate, while Zn, Cu, Ni, Cr, Pb, and Cd concentrations were within their respective normal ranges.

Of those leachate chemical constituents for which standards are available, Ca, Mg, Fe, Cu and Zn were within acceptable drinking water limits. Chloride, Na, Mn, Ni, Cr, Pb, and Cd were within acceptable irrigation water limits. Leachate losses of P, K, Al, Fe, Zn, Cu, Ni, Cr, Pb, and Cd were negligible from both soils for all treatments. Nitrogen and Ca leachate losses exceeded those of the other constituents, although no significant correlation was observed between these losses and sludge treatments or loading rates. Leachate microbial analysis during 1973 to 1974 indicated that all of the bacteria observed were of soil origin. The sludge microorganisms were retained in the top 15 cm of both soils.

REUSE OF WASTE SO_2 AND PHOSPHATE SEWAGE SLUDGES BY SOLIDIFICATION WITH LIME AND FLY ASH

Acres Consulting Services Ltd.

The phosphate-bearing sewage sludge disposal problem is becoming more acute each year. Not only are sludge volumes increasing, but disposal methods are becoming more expensive, in part because suitable landfill sites within easy hauling distance are being exhausted. These landfilled sludges are difficult to consolidate sufficiently for future use as building lots, thus reducing land use values. New, less expensive ways of disposing of phosphate-bearing sewage sludge are, therefore, urgently required.

The laboratory phase of this research work indicates the feasibility of mixing sewage sludge with certain other waste ingredients to form a self-setting mix which consolidates well and is capable of long term retention of the phosphates in a cementing matrix. The mix ingredients consisted of fly ash and SO_2 sludges from coal burning thermal power plants and spent acids from industrial processes. Hence, several waste disposal problems may be solved simultaneously. The only commercial commodity required for the process is lime which is easily obtainable and relatively inexpensive. The sludge/fly ash mixture can be produced either as a compactible mix or a liquid slurry. The compactible mix is an excellent base material for road and parking lot construction and could supplement rapidly depleting deposits of natural sand and gravel. The liquid slurry could be piped to landfill sites where it should set-up and gain sufficient strength so that these areas could be used as building sites.

The cementing matrix, when mixed with as much as 6% dry phosphate-bearing sewage sludge, will have adequate strength for highly loaded (>450 psi) landfill. Total phosphate leached during 15 days from a variety of compacted mixtures containing sewage sludge never exceeded 0.01% of the phosphate input to the mixtures.

Further laboratory research is required to determine the effect of changing the proportions of the various ingredients on long term strength gains, leaching of phosphates and survival of pathogens.

REPORT OF THE LAND DISPOSAL OF SLUDGE SUBCOMMITTEE
PROJECTS CONDUCTED 1971-1978

A significant concern that was identified by the Technical Committee of the Canada-Ontario Agreement on Great Lakes Water Quality is the disposal of municipal sludges produced from the chemical treatment of sewage for phosphorus removal. In addition, the desire to utilize this nutrient-rich material on agricultural lands, and the awareness of the possible presence of significant concentrations of toxic metals and other potentially harmful substances in sludges, has resulted in a need to conduct intensive investigation in the area of sludge disposal. The Land Disposal of Sludge Subcommittee was formed to develop a strategy for research activities, to commend and to oversee projects relating to sludge disposal, as well as to provide advice on questions referred to it.

Research Strategy of the Subcommittee

Through support of research funding provided under the Canada-Ontario Agreement, considerable research work into land disposal of sludges has been carried out in-house and through contracts.

In Ontario, a majority of the small to medium-sized pollution control plants dispose of processed sludge through application onto agricultural land. This is about 34% of all sludge produced. While sludges have been disposed of on land for many years, concerns have mainly been associated with odours. These, as well as aesthetic concerns, have resulted in political objections and subsequent local restrictions. It is only in recent years that questions have arisen concerning the potential environmental problems associated with this method of disposal. The introduction of chemical sludges from phosphorus removal facilities has raised further questions concerning this practice.

The application of sewage sludges onto agricultural lands under the proper conditions is not only economical but can result in fertilization and improve soil properties for greater uses. The widely

accepted concept of recycling is also being effected by this practice. Canada-Ontario Agreement supported research has provided a significant data base to enable the Ontario Ministry of the Environment and the Ministry of Agriculture and Food to develop guidelines for the utilization of processed sewage sludges on some agricultural lands. The guidelines will be kept under continual review and will be updated as investigations continue.

This report summarizes the research projects and conducted by the Subcommittee between 1971 and 1978.

DEVELOPMENT OF AN EFFICIENT SAMPLING STRATEGY TO CHARACTERIZE DIGESTED SLUDGES

H.D. Montecth and J.P. Stephenson
Environmental Protection Service
Environment Canada

Anaerobically digested liquid sludges from five Ontario water pollution control plants were examined to identify the sources of constituent variability (nutrients, heavy metals, physical characteristics) by determining whether variations arose from sample handling and methods of analysis, from changes in composition with time, or from inherent sludge heterogeneity. Familiar methods of data reduction (graphical time sequences, probability plots, averages, confidence limits, etc.) have been combined with more rigorous methods of data analysis (analysis of variance, time series analysis) to assist in data interpretation. The results are fundamental for establishing efficient sampling programs to monitor nutrient and undesirable contaminant discharges in sludges destined for disposal.

The greatest variability occurred within an operating day at plants hauling tank truck batches to disposal sites and at plants dewatering sludge. Variability between days was usually less than within day variability. Plants with dewatering devices processed a more homogeneous liquid sludge than plants using truck haulage.

Checks at one plant showed that significant changes had occurred in sludge parameter concentrations after five months. At a second plant, where sludge was monitored each weekday for five months, ammonia and nickel were the least variable parameters; in the same time interval other heavy metals and total solids reached independent peak concentrations.

Two years' total solids records for raw and digested sludges from two plants were examined using time series analysis. At one plant, the time series and its autocorrelation function suggested that neighbouring samples were similar, and that trends existed within the record. At the second plant, variations were random. All series were stationary with fixed means.

It is recommended that plants disposing sludge by tank trucks monitor the quality of each batch separately on a sampling day; a composite sample must be taken from the input to the tank trucks. The

precision in mean concentrations for various constituents can then be expected to be in the approximate range ±7 to ±55% within a batch with sampling at approximately two-week intervals. The greater precision (±7%) is associated with liquid phase constituents. Precisions in the range ±5 to ±16% can be achieved at plants continually withdrawing sludge to dewatering devices if a one-day composite sample is collected once every two weeks. For ammonia, one grab sample every two weeks is sufficient to estimate the mean concentration within about ±10% at either type of plant.

Residence time distribution studies indicated that primary and secondary digesters were inefficiently mixed, with only about 25% of primary digesters in the active mix state. Short circuiting was also a problem.

An ammonia gas sensing electrode was found to be fast, accurate and suitable for field determinations in the range found in sludge (100 to 1500 $mg \cdot l^{-1}$).

SLUDGE DEWATERING DESIGN MANUAL

H.W. Campbell, R.J. Rush and R. Tew
Environmental Protection Service
Environment Canada

The dewatering manual integrates bench and pilot scale data generated at the Wastewater Technology Centre with information assembled from the literature, with a view to presenting a practical step-by-step procedure for estimating the size and cost of sludge dewatering installations.

Sludge characterization tests are identified, along with a discussion of each test and its potential use for design purposes.

A procedure for estimating the quantities of primary, waste activated and digested sludge, including the contribution of sludge from phosphorus removal processes, is presented.

Process design procedures for gravity thickening, dissolved air flotation, centrifugation, vacuum filtration and pressure filtration are presented. The procedure for each dewatering method includes a description of the unit process, a discussion of applicable bench or pilot plant tests, a suggested method of scale-up and an example problem.

Cost data (December, 1975) for the major pieces of equipment required for each process have been obtained from equipment suppliers and are reported as a function of an appropriate design parameter. Operating and maintenance costs collected from the literature are summarized. A methodology for developing cost estimates is presented and illustrated with example calculations.

Research Report No. 73

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME V

T.E. Bates, E.G. Beauchamp, A. Hag, J.W. Ketcheson,
R. Protz and Y.H. Soon
Department of Land Resource Science
University of Guelph

The objective of this research was to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen, and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

This volume covers the period from April 1, 1976, to March 31, 1977 and discusses the results from the fourth year of field runoff studies with fall, winter and spring applied fluid sewage sludge on land cropped with grain corn. Nutrients and metals in runoff water were measured. The report also covers the fourth year of field rate and source studies with three sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride and aluminum sulphate for phosphorus removal. One experiment involved surface sludge applications on a loam soil on which bromegrass was grown, and two experiments involved corn on a loam, and a sandy soil. In a greenhouse experiment six fluid sewage sludges, selected for their high metal content, were applied to a soil previously adjusted to two pH levels. Eight crops of ryegrass were grown with sludges added before each crop. Half of the treatments received no sludge after the fifth crop. Crop growth and nutrient and metal uptake were studied. Field and laboratory studies have been used to estimate the nitrogen available from sludges and the rates of volatilization of nitrogen from surface applied sludge in the field.

Runoff losses continued to be small, with generally less than 1 kg N or 0.5 kg P/ha lost in one year. Rainfall and winter frost conditions appear to be more important than total precipitation in determining runoff losses. Sludge application in winter does not create added hazards provided reasonable precautions are taken.

In the field rate and source studies the bromegrass yielded slightly more with sludge than with ammonium nitrate. Corn yields were little affected by nitrogen or sludge in 1975 or 1976.

The sludges increased sodium bicarbonate-extractable (plant available) soil phosphorus markedly, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high, and little affected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application - greatest with the aluminum and iron sludges. Chromium was increased in some plant tissues at some sites, but results were inconsistent. Copper, nickel and zinc concentrations in bromegrass and corn stover increased with high rates of sludge application.

In the greenhouse study increased rates of sludge applied at one time increased the concentrations of metals in ryegrass, with the exception of mercury and selenium. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next at any of the rates studied. One exception to this was zinc, which showed some increase from the fifth to the eighth crop.

In a study of the extraction of metals from soils, it appeared that aqua regia extraction may be satisfactory as a measure of total metals added to soils in sewage sludges.

In the nitrogen field studies it was found that nitrate-N concentration in early April was higher where sludge was applied in previous years on the corn experiments, suggesting that residual sludge N was being mineralized and nitrified. The nitrate-N concentration in the soil was usually lower under grass than under corn.

Nitrogen studies on abandoned runoff plots showed increased nitrate-N concentrations in the soil on April 8 where sludge had been applied in the previous fall or winter over that present where sludge had been applied in the previous springs, but not in 1976.

SLUDGE INCINERATION AND PRECIPITANT RECOVERY: VOLUME II

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Environmental Protection Service
Fisheries and Environment Canada

In this study, multiple hearth incinerator ash produced from iron-rich primary sludge from a phosphorus removal process was leached at bench scale with various acids and alkalis to recover iron for recycle to the phosphorus removal process.

Sulphuric and hydrochloric acids produced good iron extractions. The optimum sulphuric acid concentration for leaching increased linearly with incineration temperature. For each temperature of ash there was an optimum acid concentration above which the solubility of iron decreased.

The optimum hydrochloric acid concentration for leaching showed little dependence on incineration temperature. Iron extraction increased with increasing acid concentration.

The recovery of the iron from the acid extracts in a usable form for phosphorus removal was also investigated at bench scale. The addition of concentrated sulphuric acid (98 wt%, 18 M) to the sulphuric acid leachate (31.4 vol%, 5.65 M) caused precipitation of ferric sulphate from the resultant solution (46 vol%, 8.3 M). This precipitate was then dissolved in water or effluent to give a solution usable for phosphorus removal from municipal sewage.

A preliminary cost evaluation of the iron recovery process was carried out. It showed that the ferric sulphate recovery costs were more than double the cost of commercial ferric chloride.

SLUDGE INCINERATION AND PRECIPITANT RECOVERY: VOLUME III

W.H. Schroeder and D.B. Cohen
Environmental Protection Service
Environment Canada

Samples of dewatered sludge were obtained from eight wastewater treatment plants in Ontario for laboratory scale experiments pertaining to sludge incineration. Selection of treatment plants was based on sludge type, treatment process, and the existence of sludge incineration facilities at three of these plants. Sludge types included raw primary, waste activated, and anaerobically digested mixed sludge. Four of the eight treatment plants were practicing phosphorus removal through chemical addition (alum, ferric chloride or lime).

Laboratory scale investigations consisted of determinations for total solids and volatile solids content, calorific values, tube furnace tests at temperatures over the range of 760°C (1 400°F) to 925°C (1 700°F), and thermogravimetric analyses over the temperature range from 200°C (390°F) to 925°C (1 700°F).

For the sludges investigated, total solids content ranged from 15% to 50% by weight while the volatile solids content was between 21% and 57% by weight of dry solids. Calorific values determined experimentally were compared with those calculated from three empirical equations. For seven of the eight sludges, the calculated values were within ±20% of the experimentally determined values. Tube furnace tests and thermogravimetric analyses showed that, for all samples, combustion of the organic matter was complete at 760°C (1 400°F) and that a constant weight of ash was produced for a particular sludge at combustion temperatures ranging from 760°C (1 400°F) to 925°C (1 700°F).

SLUDGE METAL SOLUBILITIES IN SOILS

M.D. Webber and G.M. Corneau

AGRICULTURE CANADA

Eight anaerobically digested Ontario sewage sludges, including two lime, four ferric chloride and two without P-removal chemicals were mixed with six soils and incubated in the laboratory under a variety of simulated field conditions. The sludges exhibited a wide range of metal contents and the soils a wide range of chemical and physical properties. Following incubation, the sludge-soil mixtures were extracted with 0.005M DTPA, 0.5N HOAc, 0.05M EDTA and 0.01M $CaCl_2$ to measure Cd, Zn, Cu, Ni, Pb, Co, Cr and Sn solubilities, and with acid ammonium oxalate, 1N $(NH_4)_2CO_3$ and 0.02M KCl to measure Mo solubility. In addition, columns of soils limed to pH 7 and treated with sludges were leached with 0.02M KCl to determine the potential for Mo movement.

Adding sludge increased the levels of extractable Cd, Zn, Cu, Ni, Pb and Mo in soils in relation to the amounts of metals added. The sludges contained small amounts of Co and caused no consistent changes in extractable Co, while Cr and Sn were not detected in any of the extracts. DTPA-extractable Zn, Ni, Pb and Co increased with increasing organic matter contents of the soils whereas DTPA- and HOAc-extractable Zn decreased with increasing clay contents.

Incubating sludge-soil mixtures under a variety of simulated field conditions indicated that the levels of extractable metals were largely independent of weather conditions likely to occur in Ontario. They were approximately the same following incubation at -15°C, 10°C, 25°C, and alternate -15°C and 25°C. Anaerobiosis generally reduced metal solubilities but is unlikely to occur widely under field conditions. Liming reduced the levels of DTPA-extractable Zn and Ni but not of Cu, Pb or Cd. Adding a large amount of newspaper to the sludge-soil mixtures caused little if any change in metal solubilities. Repeated applications of sludges containing large amounts of metals caused very high levels of extractable metals.

Leaching removed Mo from sludge treated soils and the loss was most rapid from the soil with the lowest clay and organic matter contents. No Cd was detected in the leachates.

Land application of Ontario sewage sludges will increase the solubilities of many heavy metals in soils and uncontrolled application of sludges containing large amounts of these metals will cause excessive increases. High metal solubilities in soils are likely to cause crop and animal toxicities; however, further work is required to define the critical levels. Molybdenum leached slowly from soils adjusted to pH 7 and high levels of that metal are not expected to persist in agricultural soils.

CHEMICAL SEWAGE SLUDGE DISPOSAL ON LAND (LYSIMETER STUDIES) VOLUME II

D.B. Cohen and D.M. Bryant
Environmental Protection Service
Environment Canada

Lysimeter experiments in which crops were grown on agricultural soils treated with anaerobically digested sewage sludges (from plants where phosphorus removal was being practised using metal salts) were initiated in 1972 and 1973. Alum, iron and lime treated fluid sludges were added to loamy sand and silt loam soils vegetated with orchard grass. Similarly, alum, iron and lime treated air-dried sludges were added to sand and clay soils and wheat crops were grown. The high application rates of fluid and air-dried sludges ranged from 32 to 76 and 47 to 144 tons dry wt/ha/yr, respectively. The metal loadings approximated the recommended maxima for Ontario agricultural land. The lower rates were one-third and two-thirds of the high rates. The results of these experiments are presented and compared to results from field and greenhouse studies.

There was no evidence that the aluminum, iron or lime in the digested sludges was detrimental to crop production or plant tissue quality. Orchard grass yields from the fluid sludge experiment appeared to be related to nitrogen availability. The medium sludge application rates supplied about twice as much total Kjeldahl nitrogen (TKN) as the NPK (commercial fertilizer) treatment (control) but produced similar orchard grass yields. The residual effects of cumulative applications were evident as 22% of sludge treatment yields exceeded NPK in 1973 compared to 89% in 1976. No residual effect was observed where wheat crops were grown on sand. In 1974, wheat yields from 78% of sludge treatments exceeded NPK yields, compared to 0% in 1976.

The metal contents of crops grown on the sludged soils were generally less than, or equal to, suggested maximum tolerance levels. Zinc contents increased with increasing sludge application rates and tended to increase over the four-year experimental period at all sludge application rates. Copper contents increased as sludge application rates increased, but neither copper nor cadmium increased with time.

Trends in heavy metal uptake were similar for orchard grass grown in lysimeter experiments, brome grass grown in a field experiment, and rye grass grown in a greenhouse experiment. The sludges and

application rates were similar for the lysimeter and field experiments; however, the greenhouse experiments included treatments with high application rates of sludges containing high concentrations of various heavy metals.

Leachates from both experiments exhibited heavy metal concentrations well within drking water standards and showed no increase with time. Air-dried sludge applications resulted in nitrogen availability exceeding the crop requirements and leachates exceeding the 10 mg NO_3-N/l maximum permissible concentration (MPC) for drinking water. Phosphorus concentrations in leachates from the air-dried sludge experiment were always less than the 1 mg/l effluent MPC. This was also the case for the fluid sludge experiment through 1975. By 1976, leachate phosphorus concentrations from alum sludge applications exceeded the 1 mg P/l MPC.

In general, land application of sewage sludges at rates sufficient to supply the crop uptake of N and P would limit soil heavy metal loadings to acceptable levels for the sludges used in these lysimeter studies.

SOURCES OF METALS AND METAL LEVELS IN MUNICIPAL WASTEWATERS

E.D. Atkins and J.R. Hawley
Ontario Ministry of the Environment

The main objective of this study was to compile information on typical sources of metals and metal levels in municipal wastewaters and to assess the relative benefits of point-source or end-of-the-pipe treatment for metals.

The specific metal content of a large number of Ontario sewage plant influents, sludges and effluents is recorded in detail for the first time. This was done through a detailed sampling program at selected sewage treatment plants and through a review of the records of the Ontario Ministry of the Environment. Metal removal efficiencies are also recorded and range from 35% (low estimate) for lagoon-type treatment plants to 76% for activated sludge plants.

The sewer-use by-laws of 57 Ontario municipalities were surveyed, showing that there is a wide fluctuation in metal levels allowed by them. It is recommended that these be standardized by strict implementation of a province-wide sewer-use by-law.

The complete elimination of all industrial discharges to sanitary sewers would lower metal concentrations in sewage plant influents, sludges and effluents, but the survey indicates that significant problems would still remain because of the metal content of 'domestic' sewage. A product index, in which the general chemistry of each category is summarized, and a metal index which groups household products according to their contents, are included in this report.

Research Report No. 86

NITRIFICATION-DENITRIFICATION OF WASTEWATER USING A SINGLE-SLUDGE SYSTEM: VOLUME I

A.G. Smith
ONTARIO MINISTRY OF THE ENVIRONMENT

Full-scale nitrification-denitrification of wastewater was conducted at the Newmarket, Ontario, Water Pollution Control Plant (WPCP), where primary stage lime treatment for phosphorus removal was being applied. The secondary treatment section was divided into two separate units, one for nitrification and the other for single-sludge nitrification-denitrification.

For nine months, fall to spring, the units were evaluated under ambient environmental conditions using, for the most part, on-site equipment. The object of this study was to see what degree of nitrification-denitrification could be maintained within a system with lime treatment. Experiments involved denitrification mixed liquor thickening, methanol dosing and supplementary iron salt addition for phosphorus removal.

Constant high (above 200 ml/g) sludge volume index (SVI) was experienced in both the nitrification and combined nitrification-denitrification units at Newmarket. This was thought to be caused by lime addition to the primary stage. Full nitrogen conversion and removal were disrupted by sludge chlorination for SVI control. Some limitations of the conventional facility were also found to affect nitrogen removal. Supplemental addition of ferrous sulphate, late in the program, to the aeration basin improved phosphorus removal and decreased SVI.

Subsequent pilot plant studies were carried out at Brampton and Kleinburg. In these a split-return mode of operation was evaluated under more controlled conditions. The requirements for methanol as a carbon source, process solids distribution, and post-aeration were evaluated for nitrification-denitrification under liquid temperatures ranging from 10 to 25°C.

More encouraging results were attained with the pilot unit. Denitrification solids thickening and thus improved nitrate removal was observed. Post-aeration proved necessary to maintain low effluent suspended solids, but did contribute dissolved oxygen to the denitrification tank contents.

Land application of Ontario sewage sludges will increase the solubilities of many heavy metals in soils and uncontrolled application of sludges containing large amounts of these metals will cause excessive increases. High metal solubilities in soils are likely to cause crop and animal toxicities; however, further work is required to define the critical levels. Molybdenum leached slowly from soils adjusted to pH 7 and high levels of that metal are not expected to persist in agricultural soils.

SINGLE SLUDGE NITROGEN REMOVAL SYSTEMS

P.M. Sutton, B.E. Jank and B.A. Monaghan, Environmental Protection Service, Environment Canada and K.L. Murphy, McMaster University

The need for nitrogen control in the treatment of wastewater has been well documented in numerous reports and papers. Rational design approaches have been developed for nitrification in combined and separate activated sludge systems and for denitrification in separate sludge systems receiving an external carbon and energy source. Recent attention has been focused on single sludge systems which combine the processes of carbon oxidation, nitrification, and denitrification in one or more reactors without intermediate clarification and with or without the addition of an external carbon source.

In this study, five different single sludge process configurations were studied at the pilot scale level. The effects of temperature, the aerobic to anoxic retention time ratio, the organic and inorganic loading conditions, the influent wastewater carbon to nitrogen ratio, and various other factors influencing nitrification and denitrification in single sludge systems were examined.

The results indicate that the critical factor affecting nitrification in single sludge systems is the aerobic solids retention time. The temperature influence upon nitrification in aerobic-anoxic systems and in purely aerobic systems appears to be comparable.

The denitrification rates in single sludge systems will depend on whether the reaction proceeds under non-carbon limiting or carbon limiting conditions. The organic carbon requirements in single sludge and separate sludge post-denitrification systems, to ensure no carbon limitation on the denitrification rate, are similar. In single sludge pre-denitrification and step-feed denitrification systems, the organic carbon requirements will be significantly greater.

Depending on the single sludge process configuration, the maximum effluent quality attainable in single sludge systems will be 2 to 3 mg/L of total N.

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME VI

T.E. Bates, A. Hag, J.W. Ketcheson and Y.K. Soon
Department of Land Resource Sciences
University of Guelph

The objective of this research was to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

This volume, which covers the period from April 1, 1977 to March 31, 1978, discusses the results from five years of field runoff studies with fall, winter and spring applied fluid sewage sludge on land cropped with grain corn. Nutrients and metals in runoff water were measured. The report also covers the fifth year of field rate and source studies with sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride and aluminum sulphate for phosphorus removal. One experiment involved surface sludge applications on a loam soil on which bromegrass was grown, and two experiments involved corn on a loam and a sandy loam. In a greenhouse experiment, six fluid sewage sludges, selected for their high metal content, were applied to a sandy loam soil. Eleven crops of ryegrass were grown with sludge added before each crop. Half of the treatments received no sludge after the fifth crop. Crop growth and nutrient and metal uptake were studied.

Runoff losses continued to be small, with generally less than 2 kg N or 1 kg P/ha lost in one year. Rainfall and winter frost conditions appear to be more important than total precipitation in determining runoff losses. Sludge application in winter did not create added hazards, provided reasonable precautions were taken.

In the field rate and source studies the bromegrass and corn yields were slightly more with sludge than with ammonium nitrate.

The sludges increased sodium bicarbonate-extractable (plant available) soil phosphorus markedly, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high, and little affected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application - greatest with the aluminum and iron sludges.

Chromium was increased in some plant tissues at some sites. Copper, nickel, zinc and molybdenum concentrations in bromegrass and corn stover increased with high rates of sludge application. Metal concentration in corn grain was little affected by treatment.

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass, with the exception of antimony, mercury and selenium. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next at any of the rates studied. One exception to this was zinc, which showed some increase in content from one crop to the next with one sludge very high in zinc.

The metal concentrations in ryegrass receiving different sludges frequently did not correspond to the amounts of metals added. The metals in different sludges, therefore, differ in availability either because they are in different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

Research Report No. 91

IMPACT OF NITRILOTRIACETIC ACID (NTA) ON AN ACTIVATED SLUDGE PLANT - A FIELD STUDY

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A field study on the effects of nitrilotriacetic acid (NTA) on activated sludge was carried out at the Waterdown Water Pollution Control Plant, from January, 1972 to April, 1973. The Waterdown Plant is a conventional activated sludge plant with a design flow of 1 362 m^3/d. The nominal wastewater flow was approximately 45% of design capacity and all homes served by the sewer system were within a mile and a half of the treatment plant.

The areas investigated in the study include: degradation of NTA, effect of NTA loading on chemical treatment for phosphorus removal, NTA loading and heavy metal removal in the treatment plant, and effect of NTA loading on treatment plant operation.

The NTA was added to the treatment plant in the form of Sunlight Soap (a commercial laundry detergent containing 20 wt % NTA) at two rates to approximate NTA spiking levels of 8 mg/L NTA and 16 mg/L NTA. The background NTA loading in the raw wastewater averaged 2.5 mg/L NTA. Diurnal variation studies of the NTA loading showed peak values of 12 mg/L NTA in the afternoon and minimum values of 0.1 mg/L NTA at night. The raw wastewater had an average BOD_5 of 100 mg/L, a suspended solids of 150 mg/L, and a total phosphorus loading of 6.0 mg/L P. Heavy metal levels averaged 0.2 to 0.5 mg/L for zinc, aluminum and iron, and 0.01 to 0.1 mg/L for lead, nickel and copper. The treatment plant efficiency averaged 86% BOD_5 and 85% suspended solids removal throughout the study.

Such factors as microorganism acclimatization to NTA, chemical addition for P removal, temperature and NTA loading, were analyzed by grouping the field data in such a manner that the sole effect of each factor could be analyzed with all other factors held constant. The studies demonstrated that NTA loadings up to 16 mg/L NTA did not adversely affect treatment plant efficiency or the amount of chemical precipitant required to meet an effluent total phosphorus objective of 1 mg/L P. NTA degradation was significantly affected by wastewater temperature. Correlation of heavy metal transport through the treatment plant with NTA loading was inconclusive.

Research Report No. 96

NITRIFICATION-DENITRIFICATION OF WASTEWATER USING A SINGLE SLUDGE SYSTEM: VOLUME II

A.G. Smith
Ontario Ministry of the Environment

This report describes a full-scale evaluation of the split-return mode for nitrification-denitrification of a combined domestic/industrial wastewater. The investigation, which took place from July 1974 to December 1975 at the Ontario Ministry of the Environment's Ontario Experimental Facility at Brampton, followed pilot-studies at Kleinburg, Ontario.

The evaluation investigated the effect of ferric chloride addition on phosphorous removal; the effect of solids retention times and sludge ages on nitrogen reactions at various temperatures; hydrogen peroxide addition and the use of a screen centrifuge on mixed liquor conditioning; as well as the suitability of the system for solids control and for maintenance of consistent nitrogen removal under different temperature conditions.

It was concluded that the single-sludge, split-return system gave excellent nitrogen removal with minimal methanol application. Control of solids in both aeration and denitrification basins was easily accomplished by adjusting the return-split. On-site monitoring of the process was also easily accomplished. The lack of a clearly defined temperature effect on nitrogen metabolism was attributed to the long sludge retention time inherent in the system.

Research Report No. 98

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME VII

T.E. Bates, A. Hag and Y.K. Soon
Department of Land Resource Sciences
University of Guelph

This report is a summary of results obtained from the sixth year of a nine-year research program to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface or surface waters. Two sets of experiments are described.

The first concerns field rate and source studies on the effects of treating bromegrass and corn with sludges resulting from treatment of sewage for phosphorous removal with calcium hydroxide, ferric chloride and aluminum sulphate. The effects on crop yield, plant available phosphorus, and the uptake of heavy metal ions by crops are reported and discussed.

The second was a greenhouse experiment on the growth of ryegrass treated with six fluid sludges selected for their high metal content. Crop growth, and nutrient and metal-ion uptake were studied.

In the field rate and source studies the bromegrass and corn yields were slightly higher with sludge than with ammonium nitrate application. Plant available phosphorous was increased markedly by sludge application. Heavy metal ion concentrations in plant tissue were generally increased by sludge application, while the metal concentration in corn grain was little affected.

The metal concentrations in ryegrass in the greenhouse experiments frequently did not correspond to the amounts of metals added. This was interpreted as indicating that metals in different sludges differ in their availability either because they are in different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

Research Report No. 107

SLUDGE INCINERATION AND PRECIPITANT RECOVERY
VOLUME IV: PILOT SCALE MULTIPLE-HEARTH INVESTIGATION

W.H. Schroeder, P.J. Crescuolo, H.W. Campball and D.B. Cohen
Environmental Protection Service
Environment Canada

This study describes investigations conducted at the Hamilton Water Pollution Control Plant on a pilot-scale multiple-hearth sludge incinerator. The objectives were:

1) to determine in a controlled fashion the fate of a selected number of elements with the normal ranges of operating parameters of a multiple-hearth incinerator handling municipal sewage sludge;
2) to determine the optimal and/or boundary conditions of temperature, throughput capacity (loading rate) and centre shaft speed, with regard to the prevention of clinker formation, while at the same time minimizing the residual organic content of the incinerator ash.

The experimental program consisted of a factorial design which included four levels of temperature, three levels of throughput rate, and three levels of centre shaft speed. Samples of feed, ash and scrubber water were collected at three evenly-spaced intervals throughout the steady-state operating period.

Under the constraints of the experiment, phosphorus, zinc, iron, magnesium, aluminum, nickel, copper, calcium, chromium, lead and silica proved to be conservative and remained in the ash, whereas varying proportions of cadmium, mercury and arsenic were classified into the gas stream. The destruction of total carbon was essentially complete, with the minimum level achieved being 98.7%. The most important factor in determining auxiliary fuel consumption is the water content of the feed sludge. Clinker formation was observed only under conditions of high temperature combined with long residence time within the furnace.

Research Report No. 108

LAND DISPOSAL OF SEWAGE SLUDGE: VOLUME VIII

T.E. Bates and Y.K. Soon
Department of Land Resource Science
University of Guelph

This report is a summary of results obtained during the seventh year of an eight-year research program to determine the maximum rates of sewage sludge application which can be safely used on agricultural soil. Two sets of experiments are described. One was a field study of the effects of rate and source of sludge application on corn and bromegrass. Three sludges resulting from treatment of sewage for phosphorus removal with calcium hydroxide, ferric chloride and aluminum sulphate were compared to ammonium nitrate fertilizer as sources of nitrogen, and their effects on crop yield and nutrient and metal content of crops and soil were measured. The second study was a greenhouse experiment with ryegrass as the crop and six sewage sludges selected for their high metal contents. Crop growth and nutrient and metal uptake were measured.

Yields of bromegrass and corn resulting from sludge application were at least as high as yields with ammonium nitrate. Sodium bicarbonate-extractable (plant available) soil phosphorus was increased by sludge application in the order calcium sludge > iron sludge > aluminum sludge. As in previous years, soil pH and extractable soil calcium were highest with the calcium sludge and soil pH was lowest with the iron sludge. Cadmium, copper, nickel and zinc concentrations in plant tissues were high with high sludge application rates, particularly with sludges high in these metals.

In the greenhouse experiment, after the fourteenth crop of ryegrass was harvested, the roots and shoots, and the soil on which the ryegrass was grown were analysed for metal contents. With the exception of zinc, metal concentrations were generally much higher in the root than in the shoot. The low mobility of lead and chromium in the soil-plant system was reflected in the high soil/shoot ratios of these metals. Cadmium and copper were readily absorbed by the root as indicated by the low soil/root concentration ratios, but were not so readily transported to the shoot as evidenced by relatively high root/shoot concentration ratios.

ASSESSMENT OF HEAVY METALS AND PCB's AT SELECTED SLUDGE APPLICATION SITES IN ONTARIO

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Ten sludge applications sites in Ontario were sampled during the summers of 1976 and 1978. The sites were selected to represent different locations, soil types, sludging histories and metal and PCB concentrations in sludges. Concurrently, control (i.e., no sludge) sites adjacent to each sludge application site were sampled to determine the background levels of metals and PCB's in the soils.

Until recently, few records were kept of sludge application on land in Ontario. Consequently, it was necessary to estimate the metal and PCB loadings to the sites. It was estimated that metal loadings at several locations exceeded the maxima recommended in the Ontario Sludge Utilization Guidelines.

Sludge application increased the total metal and PCB contents of soils and the largest increases generally coincided with the largest estimated loadings. DTPA-extractable metals in the soils were also increased and were well correlated with total metals in the soils.

In general, sludge application exhibited small effects on plant composition. Frequently, the differences between sites were larger than the sludge treatment effects. The most consistent effects of sludge treatment were to increase the Cd and Zn contents of plant materials. However, with a few exceptions, the increases were small and not well related to estimated metal loadings in sludge or to total or DTPA-extractable Cd and Zn in the soils. There was no consistent effect of sludge on the Cu, Ni, Pb, Mo (except at Stratford), Mn, Cr, As, Hg and PCB contents of plant materials. Stratford sludge contributed a heavy Mo loading and greatly increased the Mo content of corn leaves at that site.

Increased concentrations of Zn in plant materials resulting from sludge application are desirable because Zn tends to be deficient for plant and animal nutrition. However, increased levels of Cd are undesirable because Cd has no known biological function and it is toxic to both plants and animals. An exclusive diet of corn leaves from the Stratford sludge application site would cause molybdenosis (molybdenum-induced copper deficiency) in ruminant animals.

Results indicated that sludge application to land according to the Ontario Guidelines will not cause deleterious uptake of heavy metals by corn, oats and wheat. It appeared that the Guidelines allow an appreciable safety margin. This is desirable since sludge compositions vary widely with time.

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PARASITES AND THE LAND APPLICATION OF SEWAGE SLUDGE

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Parasite ova, mainly Ascaris and Toxocara, were recovered from many Ontario sewage sludges, and from sludged fields. These ova can survive on pasture for several years, are probably destroyed on bare soil within one year and possibly survive only a few weeks when the sludge is mixed with the soil. This information, together with the type of parasites present in Ontario and the numbers found in the digested sludge, make noticeable parasite transmission, via sludge spread on farmland, a remote possibility. Recommendations are made for the use and handling of sludge that will reduce the possibility of transmission even further.

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